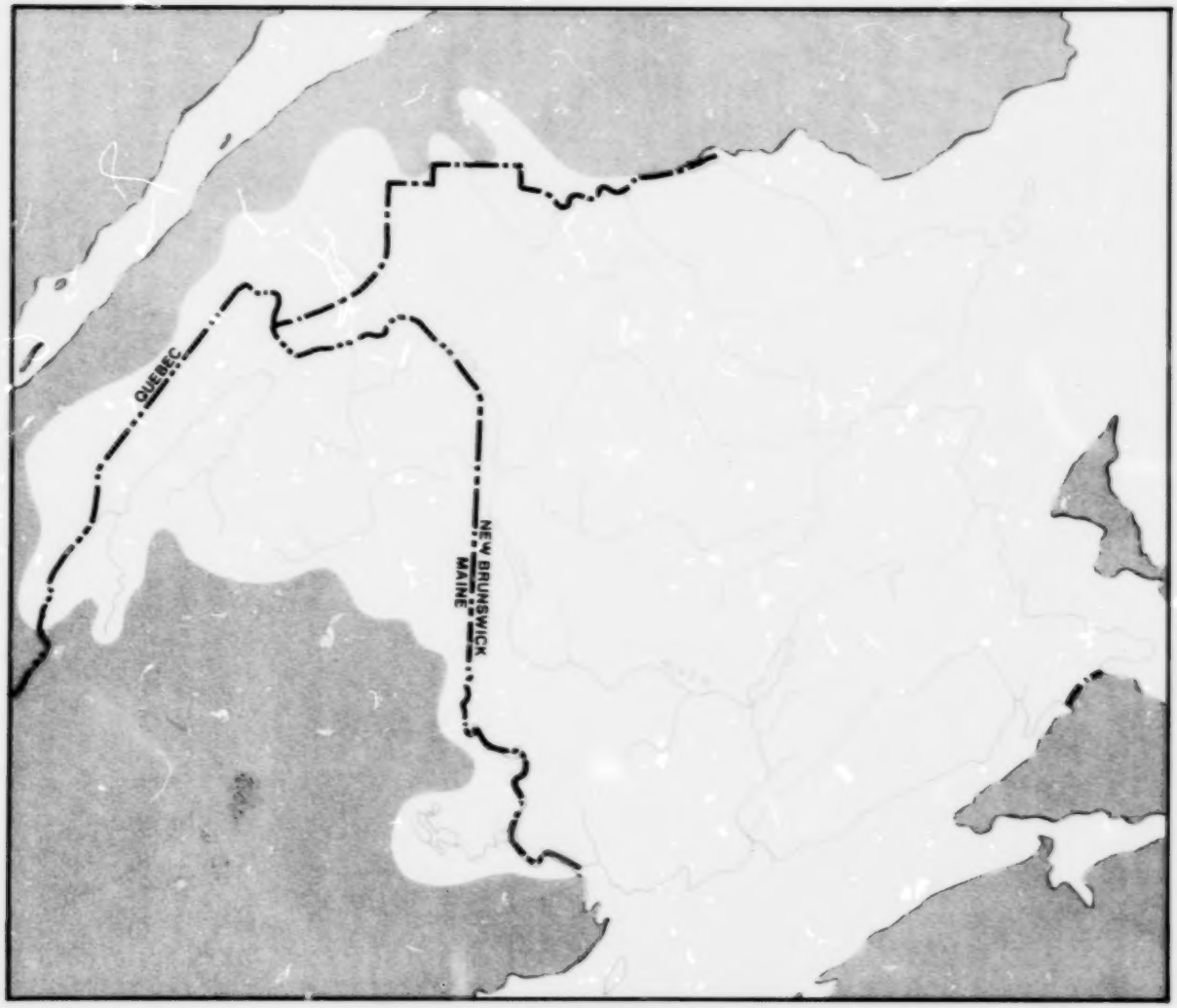
Flood Frequency Analyses New Brunswick

A Guide to the Estimation of Flood Flows For New Brunswick Rivers and Streams



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NEW BRUNSWICK FLOOD FREQUENCY ANALYSES

A GUIDE TO THE ESTIMATION OF FLOOD FLOWS FOR NEW BRUNSWICK RIVERS AND STREAMS

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Even though the techniques outlined in this report represent the current state of knowledge about flood estimation, a certain amount of uncertainty is associated with their application. Neither Environment Canada nor the New Brunswick Department of Municipal Affairs and Environment assume any liability for the misuse or misunderstanding of the information presented in this report. The user is expected to make the final evaluation of the appropriateness of the techniques and the accuracy of the data in his or her own set of circumstances.

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LIST OF SYMBOLS AND ABBREVIATIONS

a - regression coefficient for QDT equations

b - regression coefficient for QDT equations

c - envelope curve coefficient

d - envelope curve coefficient

DA - drainage area in km^2

e - regression constant for QP/QD equations

f - regression coefficient for QP/QD equations

g - regression coefficient for QP/QD equations

GEV - Generalized Extreme Value distribution

h - regression coefficient for QP/QD equations

k - regression constant for QDT equations

km^2 - square kilometres

MAP - mean annual precipitation in mm

mm - millimetres

m^3/s - cubic metres per second

QDT - daily mean flow in m^3/s of T year return period

QPT - instantaneous flow in m^3/s of T year return period

QP/QD - ratio of maximum annual instantaneous peak flow to corresponding mean daily flow

SNOW - average water content of snowpack on March 31 in mm

T - return period in years

W - Wakeby distribution

3PLN - Three-Parameter Lognormal distribution

%LS - percentage of lakes and swamps

1.0 INTRODUCTION

Flood flow estimates are required for the adequate design of hydraulic structures and for the evaluation of flood risk. As the most recent Province-wide regional analysis was conducted a decade ago (Acres Consulting Services Limited, 1977), the present study was initiated to provide updated and readily usable information for flood flow estimation. This report contains flood flow estimates for selected rivers for which streamflow records are available. It also provides a guide for the estimation of flood flows at ungauged sites along watercourses in New Brunswick.

Flood frequency analyses were performed using annual maximum daily flows for the full period of record up to and including 1985 from 63 hydrometric stations having ten or more years of record. In the first part, single station flood frequency analyses were used to obtain an estimate of peak flow for specified recurrence intervals of 2, 10, 20, 50, and 100 years. In the second part, single station flood frequency analyses from a concurrent time span (1970-1985) using historical information were performed to obtain the same flood estimates. These analyses were done with knowledge of extreme events prior to 1970.

Statistical relationships were then developed between the flood flows for specified recurrence intervals and the physiographic and hydro-climatic characteristics of the watersheds. Relationships were also found for the ratio of the instantaneous peak flows to the daily mean flows. This report presents the techniques and results of these analyses in a format which allows the information to be readily used in the estimation of flood flows for design applications and flood risk evaluation.

Figure 1 (pocket at the back) depicts the four homogeneous flood regions used in this analysis. The main stem of the Saint John River is considered separately as a fifth region. For each region, regression equations are herein presented relating flood flows of specified recurrence intervals to appropriate physiographic and hydroclimatic parameters. Equations which considered the Province, excluding the Saint John River main stem, as a single homogeneous region are also given.

To facilitate the estimation of a flood flow of a specified return period at an ungauged site, a number of techniques including proration, envelope curves and regional equations are presented. The latter technique, which is expected to be the most accurate in most instances, requires the application of the appropriate regression equation for the homogeneous region which includes the given basin.

Previous regional flood frequency analyses have been undertaken for New Brunswick, including a study completed in 1977 for the Canada-New Brunswick Flood Damage Reduction Program (Acres Consulting Services Limited, 1977). Application to flood design determination of both the index flood and direct regression methods, using maximum instantaneous and daily flood peak data, as well as pertinent hydroclimatic and physiographic data, was investigated in the 1977 report.

2.0 SINGLE STATION FLOOD FREQUENCY ANALYSES

2.1 DISCHARGE DATA BASE

The accuracy and reliability of a single station flood frequency analysis depend mainly upon the length of record and the accuracy of the existing discharge data base. For frequency analysis, records of measured streamflow longer than the return period of interest are desirable. However, the number of years of available records are often

less than the return period preferred by designers of hydraulic structures or by water resource managers. Nonetheless, the available annual maximum discharges are fitted to a frequency distribution through single station flood frequency analysis and extended in order to assess a longer return period flood.

Since hydrometric records cannot possibly exist at all points for which flood estimates are required, a data transfer technique of some sort must be developed based on the regionalization of single station frequency analyses, as was done in this investigation. For the present study, all New Brunswick natural flow hydrometric stations (i.e. those unaffected by regulation) with at least 10 years of record were examined. In addition, hydrometric stations below points where regulation was found to have an insignificant effect on flood flows and stations in Maine, Quebec, and Nova Scotia near the New Brunswick border were also considered. The 63 hydrometric stations listed in Table 1 were used, the location of which is shown in Figure 1.

2.2 FLOOD FREQUENCY ANALYSES

A single station flood frequency analysis was performed for each of the 63 stations for the annual maximum daily mean flows with the Consolidated Frequency Analysis (CFA) computer package (Pilon et al., 1985) which can fit several theoretical distributions (Three-Parameter Lognormal (3PLN), Generalized Extreme Value (GEV), Log Pearson Type III and Wakeby (W)) to the data. The coefficients of skew and kurtosis of the logarithmically transformed data, as well as the visual fit of the frequency distribution to the data were the determining factors in the distribution selection. The results of this analysis are presented in Table 2.

TABLE 1

SUMMARY OF HYDROLOGIC INFORMATION FOR

SELECTED HYDROMETRIC STATIONS

Station Number and Name		Drainage Area (Km^2)	Flood Region	Period of Record		Maximum Recorded Flow			
				Daily Means	Instantaneous	Daily		Instantaneous	
						(m^3/s)	($m^3/s/Km^2$)	(m^3/s)	($m^3/s/Km^2$)
01AD002	SAINT JOHN RIVER AT FORT KENT	14700	SAINT JOHN	1927-85	1934-70,72,73,75-85	4130	0.281	4280	0.291
01AD003	ST FRANCIS RIVER AT OUTLET OF GLASIER LAKE	1350	NORTHWESTERN	1952-85	1952-85	410	0.304	428	0.317
01AD004	SAINT JOHN RIVER AT EDMUNSTON	15500	SAINT JOHN	1968-79	1968-70,72-75,78,79	4200	0.271	4250	0.274
01AF002	SAINT JOHN RIVER AT GRAND FALLS	21900	SAINT JOHN	1931-85	1931-71,73,75-85	6250	0.285	6400	0.292
01AF003	GREEN RIVER NEAR RIVIERE-VERTE	1150	NORTHWESTERN	1963-79,81-85	1963-79,81-85	483	0.420	507	0.441
01AG002	LIMESTONE RIVER AT FOUR FALLS	199	NORTHWESTERN	1968-85	1968-79,81-85	69.9	0.351	87.2	1.247
01AG003	AROOSTOOK RIVER NEAR TINKER	6060	NORTHWESTERN	1975-85	1975-85	1530	0.252	1680	0.277
01AH005	MAMOZEKEL RIVER NEAR CAMPBELL RIVER	230	NORTHWESTERN	1973-85	1973-75,77-85	92	0.400	108	0.470
01AJ001	SAINT JOHN RIVER NEAR EAST FLORENCEVILLE	34200	SAINT JOHN	1952-85	1956-62,67,68,70,72-85	9170	0.268	9510	0.278
01AJ003	MEDUXNEKEAG RIVER NEAR BELLEVILLE	1210	NORTHWESTERN	1968-85	1968,70-85	510	0.421	600	0.496
01AJ004	BIG PRESQUE ISLE STREAM AT TRACEY MILLS	484	NORTHWESTERN	1968-85	1968-85	220	0.455	281	0.581
01AJ010	BECAQUIMEC STREAM AT COLDSTREAM	350	CENTRAL	1974-85	1974-77,79-85	140	0.400	176	0.503
01AJ011	COLD STREAM AT COLDSTREAM	156	CENTRAL	1974-85	1974-85	88.6	0.568	118	0.756
01AK001	SHOGOMOC STREAM NEAR TRANS CANADA HIGHWAY	234	NORTHWESTERN	1919-41,44-85	1968,69,71-82,84,85	117	0.500	N/A	N/A
01AK002	SAINT JOHN RIVER AT POKIOK	38900	SAINT JOHN	1919-67	1961-67	8160	0.210	N/A	N/A
01AK004	SAINT JOHN RIVER BELOW MACTAQUAC	39900	SAINT JOHN	1967-85	1967-71,73-85	11100	0.278	12300	0.308
01AK005	NORTH MASHWAAKSIS STREAM NEAR ROYAL ROAD	26.9	CENTRAL	1966-85	1966-85	14.2	0.528	32.6	1.212
01AK007	MACKAWIC RIVER NEAR TEMPERANCE VALE	240	NORTHWESTERN	1968-85	1968,69,71-85	113	0.471	147	0.613
01AK008	EEL RIVER NEAR SCOTT SIDING	531	NORTHWESTERN	1974-85	1974-84	114	0.215	117	0.220
01AL002	MASHWAAK RIVER AT DURHAM BRIDGE	1450	CENTRAL	1962-85	1965-69,71-85	827	0.570	N/A	N/A
01AL003	HAYDEN BROOK NEAR NARROWS MOUNTAIN	6.48	CENTRAL	1971-85	1971,72,74-79,81-83,85	7.76	1.198	N/A	N/A
01AL004	NARROWS MOUNTAIN BROOK NEAR NARROWS MOUNTAIN	3.89	CENTRAL	1972-85	1972,74,75,77,78,81-83,85	3.54	0.910	N/A	N/A
01AM001	NORTHWEST OROMOCTO RIVER AT TRACY	557	SOUTHERN	1963-85	1963-76,78-83	456	0.819	776	1.393
01AN001	CASTAWAY BROOK NEAR CASTAWAY	34.4	EASTERN	1977 81,83-85	1972-79,81,82,84,85	18.1	0.526	23.8	0.692
01AN002	SALMON RIVER AT CASTAWAY	1050	EASTERN	1974-85	1975-77,79,81-85	289	0.275	N/A	N/A
01AP002	CANAAN RIVER AT EAST CANAAN	668	EASTERN	1926-41,63-85	1933,1963-78,80-85	236	0.353	365	0.546
01AP004	KENNEBECASIS RIVER AT APOHAQUI	1100	SOUTHERN	1962-85	1962-77,79,81-85	520	0.473	639	0.581
01AP006	NEREPIS RIVER NEAR FOWLERS CORNER	293	SOUTHERN	1976-85	1976-79,81-85	172	0.587	281	0.959
01AQ001	LEPREAU RIVER AT LEPREAU	239	SOUTHERN	1917-85	1963-75,77-85	340	1.423 **	N/A	N/A
01AQ002	MAGAGUADAVIC RIVER AT ELMCROFT	1420	SOUTHERN	1917-22,24-33, 43-85	1966,67,69,71-77,79-82,84, 85	722	0.508	N/A	N/A
01AR006	DENNIS STREAM NEAR ST. STEPHEN	115	SOUTHERN	1967-85	1967-69,71-77,79,81-84	65.1	0.566	N/A	N/A
01AR008	BOCABEC RIVER ABOVE TIDE	43.0	SOUTHERN	1967-79	1967,68,70-77,79	34.0	0.791	53.2	1.237
01BC001	RESTIGOUCHE RIVER BELOW KEDGWICK RIVER	3160	NORTHWESTERN	1963-85	1963-85	1320	0.418	1550	0.491
01BE001	UPSALQUITCH RIVER AT UPSALQUITCH	2270	NORTHWESTERN	1919-33,44-85	1965-85	674	0.297	N/A	N/A
01BJ001	TETAGOUCHE RIVER NEAR WEST BATHURST	363	EASTERN	1923-33,52-85	1968,70-72,74,75,77,79-82, 84,85	152	0.419	N/A	N/A
01BJ003	JACQUET RIVER NEAR DURHAM CENTRE	510	EASTERN	1965-85	1965-71,73-85	195	0.382	206	0.404
01BJ004	EEL RIVER NEAR EEL RIVER CROSSING	88.6	NORTHWESTERN	1968-83	1968-81,83	47.3	0.534	60.9	0.687
01BJ007	RESTIGOUCHE RIVER ABOVE RAFTING GROUND BROOK	7740	NORTHWESTERN	1969-85	1969-85	3140	0.406	3230	0.417
01BK004	MEPISIQUIT RIVER NEAR PABINEAU FALLS	2090	CENTRAL	1958-74	1958-74	694	0.332	801	0.383
01BL001	BASS RIVER AT BASS RIVER	175	EASTERN	1966-85	1966-69,71-85	110	0.629	129	0.737
01BL002	SOUTHWEST CARAQUET RIVER AT BURNSVILLE	173	EASTERN	1970-85	1971-85	91.2	0.527	109	0.618
01BL003	TRACADIE RIVER AT MURPHY BRIDGE CROSSING	383	EASTERN	1971-85	1971-85	162	0.423	187	0.488

TABLE 1 (Cont'd)

SUMMARY OF HYDROLOGIC INFORMATION FOR

SELECTED HYDROMETRIC STATIONS

Station Number	Station Name	Drainage Area (Km^2)	Flood Region	Period of Record: Daily Means	Period of Record: Instantaneous	Maximum Recorded Flow: Daily (m^3/s)	Maximum Recorded Flow: Daily ($m^3/s/Km^2$)	Maximum Recorded Flow: Instantaneous (m^3/s)	Maximum Recorded Flow: Instantaneous ($m^3/s/Km^2$)
01B0001	SOUTHWEST MIRAMICHI RIVER AT BLACKVILLE	5050	CENTRAL	1919-33,39, 62-85	1964-75,77-81,83-85	2190	0.434	2790	0.552
01B0002	RENOUS RIVER AT MCGRAW BROOK	611	CENTRAL	1966-85	1966-73,75-80,82-85	320	0.524	697	1.141
01B0003	BARNABY RIVER BELOW SEMIWAGAN RIVER	484	EASTERN	1973-85	1973-75,77-85	186	0.384	204	0.421
01BP001	LITTLE SOUTHWEST MIRAMICHI RIVER AT LYTTLETON	1340	CENTRAL	1952-85	1967-69,71-76,78,80-82,84,85	861	0.643	N/A	N/A
01BQ001	NORTHWEST MIRAMICHI RIVER AT TROUT BROOK	948	CENTRAL	1962-85	1962 69,71-75,77,78,80-83,85	487	0.514	N/A	N/A
01BR001	KOUCHIBOUGUAC RIVER NEAR VAUTOUR	177	EASTERN	1931,32,70-85	1971-85	59.5	0.336	66.0	0.373
01BS001	COAL BRANCH RIVER AT BEERSVILLE	166	EASTERN	1964-85	1964-69,71-85	67.4	0.406	83.3	0.502
01BU002	PETITCODIAC RIVER NEAR PETITCODIAC	391	EASTERN	1962-85	1962-75,77-79,81-85	210	0.537	260	0.665
01BU003	TURTLE CREEK AT TURTLE CREEK	129	SOUTHERN	1963-85	1964-85	76.7	0.595	N/A	N/A
01BU004	PALMER'S CREEK NEAR DORCHESTER	34.2	SOUTHERN	1967-84	1967-77,79-84	27.9	0.816	47.6	1.392
01BV005	RATCLIFFE BROOK BELOW OTTER LAKE	29.3	SOUTHERN	1961-71	1964-69,71	29.7	1.014	N/A	N/A
01BV006	POINT WOLFE RIVER AT FUNDY NATIONAL PARK	130	SOUTHERN	1964-85	1964-80,83-85	118	0.908	172	1.323
01BV007	UPPER SALMON RIVER AT ALMA	181	SOUTHERN	1968-79	1968,71-78	154	0.851	236	1.304
1010000	SAINT JOHN RIVER AT NINEMILE BRIDGE, MAINE	3513	SAINT JOHN	1951-84	1951-84	1090	0.310	1260	0.359
1010500	SAINT JOHN RIVER AT DICKEY, MAINE	7022	SAINT JOHN	1947-83	1947-83	2460	0.350	2600	0.370
1013500	FISH RIVER NEAR FORT KENT, MAINE	2287	NORTHWESTERN	1904-08,30-83	1930-83	442	0.193	448	0.196
1016500	MACHIAS RIVER NEAR ASHLAND, MAINE	855	NORTHWESTERN	1952-83	1952-81,83	374	0.437	470	0.550
1017900	MARLEY BROOK NEAR LUDLOW, MAINE	3.81	NORTHWESTERN	1965-82	1965-82	2.47	0.648	9.49	2.491*
1018000	MEDUXNEKEAG RIVER NEAR HOULTON, MAINE	453	NORTHWESTERN	1942-82	1942-82	170	0.375	188	0.415
01BD002	MATAPEDIA EN AMONT DE LA RIVIERE ASSEMETQUAGAN, QUEBEC	2770	NORTHWESTERN	1970-84	1971-77,80,81	940	0.339	N/A	N/A
01DL001	KELLEY RIVER AT EIGHT MILE FORD, N.S.	63.2	SOUTHERN	1970-85	1972-85	47.3	0.748	65.1	1.030
01BF001	NOUVELLE AU PONT, QUEBEC	1140	NORTHWESTERN	1964-85	1965-77,79-85	508	0.446	566	0.496

* Extreme maximum instantaneous recorded flow in $m^3/s/Km^2$.

** Extreme maximum daily recorded flow in $m^3/s/Km^2$.

N/A The maximum recorded instantaneous flow corresponding to the maximum recorded daily flow was not available.

Note: Stations having a period of record to 1985 may still be operational.

TABLE 2

RESULTS OF SINGLE STATION FLOOD FREQUENCY ANALYSES FOR ENTIRE PERIOD OF RECORD

STATION	QP/QD RATIO	NUMBER OF FLOOD PEAKS	YEARS OF RECORD	DISTRIBUTION[6]	DAILY MEAN MAXIMUM FLOW QD2 (m^3/s)	QD10 (m^3/s)	QD20 (m^3/s)	QD50 (m^3/s)	QD100 (m^3/s)
01AD002 SAINT JOHN	1.03	50	59	3PLN	2310	3360	3720	4170	4490
01AD003 ST FRANCIS	1.02	34	34	3PLN	207	331	376	434	478
01AD004 SAINT JOHN	1.02	9	12	3PLN	2900	3860	4280		
01AF002 SAINT JOHN	1.10	53	55	3PLN	3210	4890	5480	6220	6760
01AF003 GREEN	1.06	22	22	3PLN	224	371	422	485	531
01AG002 LIMESTONE	1.25	17	18	3PLN	32.9	50.3	57.7	67.7	75.6
01AG003 AROOSTOOK	1.17	11	11	3PLN	938	1540	1780		
01AH005 MAMOZEKEL	1.18	12	13	W	43.1	69.8	83.0		
01AJ001 SAINT JOHN[1]	1.04	24	34	3PLN	4690	7110	7830	8660	9220
01AJ003 MEDUXNEKEAG	1.15	17	18	3PLN	245	418	486	575	642
01AJ004 BIG PRESQUE ISLE[2]	1.18	18	18	3PLN	92.1	147	170	200	224
01AJ010 BECAQUIMEC	1.16	11	12	3PLN	77.4	128	146		
01AJ011 COLD STREAM	1.38	12	12	3PLN	72.5	66.5	82.7		
01AK001 SHOGOMOC	1.03	16	64	3PLN	37.6	60.5	69.2	80.4	88.9
01AK004 SAINT JOHN[3]	1.06	25	66	3PLN	5340	7760	8590	9610	10300
01AK005 NORTH NASHWAAKSIS	1.48	20	20	3PLN	5.89	10.7	13.0	16.4	19.2
01AK007 NACKAMIC	1.13	17	18	3PLN	51.9	88.3	103	123	139
01AK008 KEL	1.03	12	12	3PLN	68.7	102	113		
01AL002 NASHWAAK	1.15	20	24	3PLN	293	585	722	918	1080
01AL003 HAYDEN	1.80	12	15	W	2.23	4.32	5.61		
01AL004 NARROWS MTN.	1.65	9	14	W	1.14	2.48	3.19		
01AM001 N.W. OROMOCTO	1.27	20	23	3PLN	109	241	329	484	636
01AN001 CASTAWAY	1.32	11	13	W	9.38	13.4	15.9		
01AN002 SALMON	1.17	9	12	3PLN	195	273	309		
01AP002 CANAAN	1.18	22	38	3PLN	141	200	219	240	255
01AP004 KENNEBECASIS	1.22	22	24	3PLN	229	444	544	688	807
01AP006 NEREPIS	1.59	9	10	W	75.1	137	167		
01AQ001 LEPREAU	1.21	22	69	3PLN	66.2	133	166	217	261
01AQ002 MAGAGUADAVIC	1.08	16	58	3PLN	227	370	429	509	571
01AR006 DENNIS[4]	1.29	15	19	GEV	25.1	37.5	42.7		
01AR008 BOCABEC	1.31	11	13	W	10.8	21.3	27.4		
01BC001 RESTIGOUCHE	1.04	23	23	3PLN	567	962	1110	1310	1460
01BE001 UPSALQUITCH	1.07	21	57	3PLN	339	552	635	746	831
01BJ001 TETAGOUCHE	1.12	13	45	3PLN	72.7	109	121	137	148
01BJ003 JACQUET	1.20	20	21	3PLN	114	158	171	187	197
01BJ004 KEL	1.15	15	16	3PLN	25.7	43.0	52.0	65.6	77.5
01BJ007 RESTIGOUCHE	1.07	17	17	3PLN	1540	2590	2990	3520	3930
01BK004 MEPISIQUIT	1.09	17	17	3PLN	344	636	763	937	1080
01BL001 BASS	1.15	19	20	3PLN	40.5	68.6	81.0	98.4	112
01BL002 SOUTHWEST CARAQUET	1.19	15	16	GEV	34.1	61.4	80.1		
01BL003 TRACADIE	1.07	15	15	W	72.1	107	130		
01BO001 S.W. MIRAMICHI	1.13	20	40	3PLN	842	1390	1600	1880	2090
01BO002 RENOUS	1.21	18	20	3PLN	131	242	300	387	462
01BO003 BARNABY	1.09	12	13	3PLN	96.0	175	210		

TABLE 2 (cont'd)

RESULTS OF SINGLE STATION FLOOD FREQUENCY ANALYSES FOR ENTIRE PERIOD OF RECORD

STATION		QP/QD RATIO	NUMBER OF FLOOD PEAKS	YEARS OF RECORD	DISTRIBUTION[6]	DAILY MEAN MAXIMUM FLOW QD2 (m^3/s)	QD10 (m^3/s)	QD20 (m^3/s)	QD50 (m^3/s)	QD100 (m^3/s)
01BP001	LITTLE S.W. MIRAMICHI	1.10	15	34	3PLN	231	476	605	804	978
01BQ001	N.W. MIRAMICHI[5]	1.16	20	24	3PLN	189	337	397	476	537
01BR001	KOUCHIBOUGUAC	1.22	15	18	3PLN	34.9	60.4	74.2	95.6	114
01BS001	COAL BRANCH	1.30	21	22	3PLN	45.3	63.3	68.8	75.4	79.9
01BU002	PETITCODIAC	1.28	22	24	W	88.4	132	156		
01BU003	TURTLE	1.45	22	23	3PLN	38.3	61.5	70.4	82.0	90.9
01BU004	PALMER'S	1.87	17	18	3PLN	12.8	22.2	25.9	30.6	34.2
01BV005	RATCLIFFE	1.36	7	11	3PLN	12.3	26.0	32.2		
01BV006	POINT WOLFE	1.97	20	22	3PLN	58.0	96.9	113	135	152
01BV007	UPPER SALMON	2.26	9	12	3PLN	82.3	142	167		
1010000	SAINT JOHN	1.05	34	34	3PLN	671	947	1030	1130	1190
1010500	SAINT JOHN	1.06	37	37	3PLN	1310	2090	2410	2830	3150
1013500	FISH	1.01	58	59	3PLN	232	329	360	395	420
1016500	MACHIAS	1.07	31	32	3PLN	159	279	333	407	467
1017900	MARLEY	2.37	18	18	3PLN	1.11	2.19	2.73	3.55	4.25
1018000	MEDUXNEKEAG	1.08	41	41	3PLN	89.3	148	170	199	220
01BD002	MATAPEDIA	1.04	9	15	3PLN	449	666	782	963	1120
01DL001	KELLEY	1.59	14	16	3PLN	23.0	40.9	48.7	59.5	68.1
01BF001	NOUVELLE	1.10	20	22	3PLN	265	412	465	553	583

1. Frequency analysis with historical information based on long-term record at 01AK002 and 01AK004.
2. Frequency analysis with historical information based on long-term record at 01AK001.
3. Combined records at 01AK002 and 01AK004.
4. Frequency analysis with historical information based on long-term record at 01AQ001.
5. Frequency analysis with historical information based on long-term record at 01BP001.
6. 3PLN is Three-Parameter Lognormal; W is Wakeby; GEV is Generalized Extreme Value.

NOTE: QD50 and QD100 values were not included for hydrometric stations where there existed insufficient confidence in their estimation. It is always possible for the user to obtain the most recent annual maximum daily mean flows from the Inland Waters Directorate in order to perform his/her own single station flood frequency analyses.

For full station name, please refer to Table 1.

Due to the difference in flow regime between the 1970s and the earlier periods, single station flood frequency analyses were also performed on 37 stations using a common period of record from 1970 to 1985. In order to effectively increase the length of record, historical information based on the long-term records at each station or nearby stations were employed where warranted and where possible to establish a more realistic return period for extreme events. These 37 frequency analyses were used to develop the regional flood frequency equations for the 2, 10, 20, 50, and 100 year floods on a Province-wide basis as well as for each of the homogeneous flood regions. The results of the single station flood frequency analyses for the 1970 to 1985 period are presented in Table 3.

2.3 PERIOD OF RECORD CONSIDERATIONS

Since it became apparent that, in general, the flood flow regime during the period 1970-85 was significantly different than the period which preceded it, it was thus considered inappropriate to mix samples which cover differing periods of record in developing regional flood frequency relationships. It was felt that samples from different periods violated some of the basic criteria used in flood frequency analysis including homogeneity and stationarity. Admittedly, the period 1970-85 was chosen somewhat arbitrarily and is based as much on the availability of hydrometric record as any other single consideration. However, despite a reduction in sample size, the results of the regional analyses using this common period were marginally better than a similar analysis using the entire period of record up to 1985 at each station.

TABLE 3

RESULTS OF SINGLE STATION FLOOD FREQUENCY ANALYSES

USING 1970-85 PERIOD WITH HISTORICAL ANALYSIS

Station	Daily Mean Maximum Flow QD2 (m^3/s)	QD10 (m^3/s)	QD20 (m^3/s)	QD50 (m^3/s)	QD100 (m^3/s)
01AD002	2550	3240	3460	3720	3900
01AD003	243	338	366	399	422
01AF002	3600	4840	5240	5720	6070
01AF003	234	355	402	464	512
01AG002	34.3	50.4	57.2	66.7	74.1
01AJ001	5470	7470	8120	8910	9460
01AJ003	243	415	482	570	637
01AJ004	93.6	148	170	199	222
01AK001	37.7	55.9	61.4	67.8	72.1
01AK004	6090	8360	9160	10200	10900
01AK005	6.20	11.1	13.4	16.6	19.2
01AK007	54.4	89.3	103	120	133
01AL002	315	584	705	876	1010
01AM001	130	298	358	422	460
01AP002	151	198	211	226	235
01AP004	234	412	493	610	705
01AQ001	63.4	112	135	169	197
01AR006	25.7	41.9	48.7	57.2	63.3
01BC001	591	965	1130	1350	1530
01BD002	449	666	782	963	1120
01BE001	394	549	594	645	679
01BF001	283	415	459	513	552
01BJ001	78.4	104	112	121	127
01BJ003	119	159	171	185	195
01BJ007	1480	2490	2880	3400	3800
01BL001	42.8	74.4	88.0	107	122
01BL002	34.3	64.4	81.9	110	136
01BO001	971	1520	1700	1930	2100
01BO002	145	244	289	353	406
01BP001	238	425	528	691	837
01BQ001	221	360	411	475	523
01BR001	34.6	63.3	79.9	107	131
01BS001	45.3	64.3	72.2	82.8	91.2
01BU004	11.9	21.0	24.8	29.8	33.7
01BV006	59.0	93.8	108	128	144
01DL001	23.0	40.9	48.7	59.5	68.1
1010000	808	992	1040	1080	1100

N.B.: The Three-Parameter Lognormal was the selected distribution for all stations except 01AR006 Dennis Stream near St. Stephen and 01AM001 Northwest Oromocto River at Tracy where the Wakeby was selected due to an extremely poor visual fit to the 3PLN. Historical information based on the long-term records or nearby stations were employed where possible.

It would have been possible to derive regional equations for the Saint John River main stem based on a much longer common period of record. However, statistical testing of the data bases of maximum daily mean flows revealed at many stations either a trend or a change in mean when the record was divided in two parts of equal length. This further confirmed our concerns about the different flow regimes in New Brunswick.

3.0 REGIONAL FLOOD FREQUENCY ANALYSIS

3.1 METHOD OF ANALYSIS

Because watershed and flood generating characteristics differ from one drainage basin to another, the results of a single station flood frequency analysis are only applicable to locations on the same stream at or near the hydrometric station or for similar nearby basins. However, the majority of water resource projects are usually undertaken where proration is not applicable Therefore, regional relationships were developed in order to obtain flood estimates at ungauged sites. Relationships were found for the entire Province as well as for homogeneous flood zones with similar physiographic and climatic characteristics.

The determination of these homogeneous flood zones for New Brunswick involved the use of a computer program called RFA3LN (R. Condie and K.D. Harvey, 1985) based on the index flood approach. Using statistical comparisons of dimensionless flood ratios, as well as physiographic/climatic similarities, initial regions were defined. A regional regression equation for the two year return period flood was then determined for each of the regions and the regional and single station flood flow estimates for stations near regional boundaries were compared. This led to further modification of the homogeneous flood regions and thus the regional boundaries were finalized.

For New Brunswick, five homogeneous flood regions have been defined (Figure 1) for which flood flow relationships were developed. These are referred to as the Eastern, Southern, Central, Northwestern and Saint John River main stem regions.

3.2 REGRESSION ANALYSIS RESULTS

Regional regression analysis consists of finding a relationship between the flood flows of a given return period at locations with streamflow records and physiographic and/or climatic variables (Table 4) describing the watersheds draining to those locations. Flood estimates determined from single station frequency analyses for a common period of record (1970-85) were selected in order to provide a uniform base for comparison because the 1970s are known to have been high flow years throughout the Province of New Brunswick.

With the logarithm of the flow as the dependent variable and the logarithms of the physiographic/climatic factors as the independent variables, a stepwise multiple regression was performed using the data in Tables 3 and 4. Table 5 provides the equations for the 2, 10, 20, 50, and 100 year return periods respectively, which are in the following form:

$$\log_{10} QDT = k + a \log_{10} DA + b \log_{10} MAP \qquad (1)$$

where QDT is the annual maximum daily mean flow (m^3/s) with a recurrence interval of T years;

k is the regression constant;

a and b are the regression coefficients;

DA is the drainage area (km^2); and

MAP is the mean annual precipitation (mm).

TABLE 4

SUMMARY OF
PHYSIOGRAPHIC/CLIMATIC DATA
FOR SELECTED HYDROMETRIC STATIONS

STATION		DRAINAGE AREA (Km^2)	PERCENTAGE OF LAKES+SWAMPS	MEAN ANNUAL PRECIPITATION (mm)	AVG. WATER CONTENT OF SNOW COVER ON MARCH 31 (mm)
01AD002	SAINT JOHN RIVER AT FORT KENT	14700	5.71	997	231
01AD003	ST FRANCIS RIVER AT OUTLET OF GLASIER LAKE	1350	2.81	1060	224
01AD004	SAINT JOHN RIVER AT EDMUNDSTON	15500	5.56	1010	232
01AF002	SAINT JOHN RIVER AT GRAND FALLS	21900	4.90	1010	231
01AF003	GREEN RIVER AT RIVIERE-VERTE	1150	1.21	1070	252
01AG002	LIMESTONE RIVER AT FOUR FALLS	199	9.78	975	159
01AG003	AROOSTOOK RIVER NEAR TINKER	6060	5.83	934	190
01AH005	MAMOZEKEL RIVER NEAR CAMPBELL RIVER	230	0.04	1030	198
01AJ001	SAINT JOHN RIVER NEAR EAST FLORENCEVILLE	34200	4.97	1010	217
01AJ003	MEDUXNEKEAG RIVER NEAR BELLEVILLE	1210	5.61	958	157
01AJ004	BIG PRESQUE ISLE STREAM AT TRACEY MILLS	484	3.70	925	140
01AJ010	BECAQUIMEC STREAM AT COLDSTREAM	350	0.77	1130	126
01AJ011	COLD STREAM AT COLDSTREAM	156	0.08	1100	129
01AK001	SHOGOMOC STREAM NEAR TRANS CANADA HIGHWAY	234	11.9	1120	147
01AK004	SAINT JOHN RIVER BELOW MACTAQUAC	39900	5.33	1010	205
01AK005	NORTH WASHWAAKSIS STREAM NEAR ROYAL ROAD	26.9	2.16	1220	145
01AK007	WACKAWIC RIVER NEAR TEMPERANCE VALE	240	5.11	1060	129
01AK008	EEL RIVER NEAR SCOTT SIDING	531	13.3	1070	142
01AL002	WASHWAAK RIVER AT DURHAM BRIDGE	1450	1.39	1210	167
01AL003	HAYDEN BROOK NEAR NARROWS MOUNTAIN	6.48	0.56	1230	190
01AL004	NARROWS MOUNTAIN BROOK NEAR NARROWS MOUNTAIN	3.89	0.61	1230	190
01AM001	NORTHWEST OROMOCTO RIVER AT TRACY	557	15.1	1150	117
01AN001	CASTAWAY BROOK NEAR CASTAWAY	34.4	6.60	1180	130
01AN002	SALMON RIVER NEAR CASTAWAY	1050	6.41	1130	146
01AP002	CANAAN RIVER AT EAST CANAAN	668	3.57	1040	137
01AP004	KENNEBECASIS RIVER AT APOHAQUI	1100	0.72	1190	108
01AP006	NEREPIS RIVER NEAR FOWLERS CORNER	293	1.28	1140	110
01AQ001	LEPREAU RIVER AT LEPREAU	239	10.2	1240	101
01AQ002	MAGAGUADAVIC RIVER AT ELMCROFT	1420	7.39	1175	126
01AR006	DENNIS STREAM NEAR ST. STEPHEN	115	8.37	1160	110
01AR008	BOCABEC RIVER ABOVE TIDE	43.0	6.44	1180	85
01BC001	RESTIGOUCHE RIVER BELOW KEDGWICK RIVER	3160	0.73	1140	240
01BE001	UPSALQUITCH RIVER AT UPSALQUITCH	2270	0.63	1080	232
01BJ001	TETAGOUCHE RIVER NEAR WEST BATHURST	363	2.24	988	235
01BJ003	JACQUET RIVER NEAR DURHAM CENTRE	510	2.00	1050	235
01BJ004	EEL RIVER NEAR EEL RIVER CROSSING	88.6	0.68	1100	216
01BJ007	RESTIGOUCHE RIVER ABOVE RAFTING GROUND BROOK	7740	0.77	1120	224
01BK004	NEPISIQUIT RIVER NEAR PABINEAU FALLS	2090	2.35	1010	241
01BL001	BASS RIVER AT BASS RIVER	175	8.11	1010	209
01BL002	SOUTHWEST CARAQUET RIVER AT BURNSVILLE	173	10.4	1130	194
01BL003	TRACADIE RIVER AT MURPHY BRIDGE CROSSING	383	2.34	1090	204
01BO001	SOUTHWEST MIRAMICHI RIVER AT BLACKVILLE	5050	3.52	1090	177
01BO002	RENOUS RIVER AT MCGRAW BROOK	611	6.22	1180	199
01BO003	BARNABY RIVER BELOW SEMIWAGAN RIVER	484	10.7	1080	170
01BP001	LITTLE SOUTHWEST MIRAMICHI RIVER AT LYTTLETON	1340	5.06	1180	222
01BQ001	NORTHWEST MIRAMICHI RIVER AT TROUT BROOK	948	3.96	1130	213
01BR001	KOUCHIBOUGUAC RIVER NEAR VAUTOUR	177	11.7	1050	161
01BS001	COAL BRANCH RIVER AT BEERSVILLE	166	5.23	1070	150
01BU002	PETITCODIAC RIVER NEAR PETITCODIAC	391	0.76	1030	124
01BU003	TURTLE CREEK NEAR TURTLE CREEK	129	0.31	1310	125
01BU004	PALMER'S CREEK NEAR DORCHESTER	34.2	0.15	1210	98
01BV005	RATCLIFFE BROOK BELOW OTTER LAKE	29.3	3.14	1410	108
01BV006	POINT WOLFE RIVER AT FUNDY NATIONAL PARK	130	1.05	1390	140
01BV007	UPPER SALMON RIVER AT ALMA	181	0.54	1380	144
1010000	SAINT JOHN RIVER AT NINEMILE BRIDGE, MAINE	3513	3.43	1070	245
1010500	SAINT JOHN RIVER AT DICKEY, MAINE	7022	2.70	1030	239
1013500	FISH RIVER NEAR FORT KENT, MAINE	2287	15.1	928	223
1016500	MACHIAS RIVER NEAR ASHLAND, MAINE	855	6.66	943	218
1017900	MARLEY BROOK NEAR LUDLOW, MAINE	3.81	4.20	975	170
1018000	MEDUXNEKEAG RIVER NEAR HOULTON, MAINE	453	10.3	999	164
01BD002	MATAPEDIA EN AMONT DE LA RIVIERE ASSEMETQUAGAN, QUEBEC	2770	2.54	1040	265
01DL001	KELLEY RIVER AT EIGHT MILE FORD, N.S.	63.2	4.29	1250	100
01BF001	NOUVELLE AU POINT, QUEBEC	1140	0.17	1060	228

TABLE 5

REGIONAL REGRESSION EQUATIONS

$$\log_{10}QDT = k + a\log_{10}DA + b\log_{10}MAP$$

Return Period (yrs)	Region	k	a	b	Multiple r-square	Standard Error (%)
2	Province	-0.420	0.913	-	0.978	+21.3, -17.6
		-4.146	0.933	1.206	0.984	+18.1, -15.4
	Eastern	-0.650	1.001	-	0.962	+13.8, -12.1
	Central	-0.570	0.965	-	0.997	+11.8, -10.6
	Southern	-0.181	0.840	-	0.957	+26.7, -21.1
		-10.626	0.894	3.343	0.993	+10.8, - 9.8
	Northwestern	-0.706	0.995	-	0.987	+14.6, -12.7
	Saint John main stem	-0.062	0.836	-	0.999	+ 2.8, - 2.7
10	Province	-0.146	0.888	-	0.967	+26.3, -20.8
		-5.696	0.918	1.797	0.981	+19.7, -16.5
	Eastern	0.059	0.786	-	0.974	+ 8.8, - 8.1
	Central	-0.290	0.949	-	0.996	+11.8, -10.6
	Southern	-0.021	0.881	-	0.957	+28.0, -21.8
	Northwestern	-0.548	1.004	-	0.980	+19.2, -16.1
	Saint John main stem	-0.142	0.882	-	0.998	+ 4.1, - 3.9
20	Province	-0.055	0.878	-	0.960	+29.1, -22.5
		-6.170	0.910	1.980	0.977	+21.6, -17.8
	Eastern	0.368	0.684	-	0.957	+ 9.9, - 9.0
	Central	-0.190	0.939	-	0.996	+12.6, -11.2
	Southern	0.039	0.887	-	0.958	+28.0, -21.9
	Northwestern	-0.509	1.009	-	0.976	+20.9, -17.3
	Saint John main stem	-0.188	0.901	-	0.998	+ 4.4, - 4.3

TABLE 5 (cont'd)

REGIONAL REGRESSION EQUATIONS

$$\log_{10}QDT = k + a\log_{10}DA + b\log_{10}MAP$$

Return Period (yrs)	Region	k	a	b	Multiple r-square	Standard Error (%)
50	Province	0.052	0.864	-	0.948	+33.3, -25.0
		-6.759	0.900	2.206	0.970	+24.9, -19.9
	Eastern	0.759	0.552	-	0.872	+14.7, -12.9
	Central	-0.078	0.930	-	0.994	+15.4, -13.3
		-11.195	0.986	3.571	0.999	+ 7.9, - 7.3
	Southern	0.110	0.892	-	0.958	+28.2, -22.0
	Northwestern	-0.470	1.017	-	0.972	+23.3, -18.9
	Saint John main stem	-0.269	0.928	-	0.998	+ 4.5, - 4.3
100	Province	0.124	0.855	-	0.937	+37.0, -27.0
		-7.150	0.894	2.355	0.962	+28.1, -22.0
	Eastern	1.046	0.454	-	0.733	+19.5, -16.3
	Central	-0.001	0.923	-	0.991	+18.4, -15.5
		-13.873	0.993	4.456	0.999	+ 7.0, - 6.5
	Southern	0.162	0.893	-	0.957	+28.6, -22.2
	Northwestern	-0.447	1.023	-	0.968	+25.3, -20.2
	Saint John main stem	-0.311	0.943	-	0.998	+ 4.6, - 4.4

Other physiographic and climatic variables such as area of lakes and swamps, slope, shape factor, length of stream and average water content of the snow cover were examined, but they did not further explain flood magnitudes in the regional equations.

The regression analysis was not only performed for the entire Province but also for each homogeneous flood region. Because of the large drainage areas of the Saint John River hydrometric stations, a single Saint John River station, Saint John River at Nine Mile Bridge, was used to develop the Province-wide equation. The equations at various steps before the final equation, which are useful in obtaining a flood estimate more readily, are also provided in Table 5. It is left to the user to decide whether the gain in accuracy is worth the effort to derive further physiographic/climatic data.

The coefficient of determination, r-square, which is an expression of the amount of linear relationship between dependent and independent variables, and the standard error of estimate are also provided in Table 5.

The developed equations are very sensitive to mean annual precipitation (MAP) and to a lesser degree to drainage area (DA). A 5% error in estimating MAP can lead to a 20% error in flood estimation, while a 5% error in estimating DA will result in an error of about 5%. Equations with larger regression coefficients are more sensitive to the variables with the larger coefficients.

Table 6 indicates the range of the physiographic/climatic variables that were used to derive the equations. The equations should not be applied outside the range used to develop them. Since the equations provide better estimates near the mid-range of the parameters,

TABLE 6

RANGE OF INDEPENDENT VARIABLES USED IN REGRESSION EQUATIONS

Region	Type of Equation	Range	Number of Stations
Province	QD2 - QD100	26.9 km^2 < DA < 7740 km^2	33
	QD2 - QD100	925 mm < MAP < 1390 mm	33
	QP/QD	3.81 km^2 < DA < 7740 km^2	55
Eastern	QD2 - QD100	166 km^2 < DA < 668 km^2	7
	QP/QD	34.4 km^2 < DA < 1050 km^2	11
	QP/QD	130 mm < SNOW < 235 mm	11
Central	QD2 - QD100	26.9 km^2 < DA < 5050 km^2	6
	QD2 - QD100	1095 mm < MAP < 1220 mm	6
	QP/QD	26.9 km^2 < DA < 5050 km^2	10
Southern	QD2 - QD100	34.2 km^2 < DA < 1100 km^2	7
	QD2 - QD100	1153 mm < MAP < 1390 mm	7
	QP/QD	29.3 km^2 < DA < 1420 km^2	12
	QP/QD	0.15% < %LS < 15.1%	12
Northwestern	QD2 - QD100	199 km^2 < DA < 7740 km^2	12
	QP/QD	3.81 km^2 < DA < 7740 km^2	19
Saint John main stem	QD2 - QD100	3510 km^2 < DA < 39900 km^2	5

greater uncertainty is associated with flood estimates using values of DA or MAP near the upper or lower limits.

Caution must be exercised when applying the equations to an urbanized or clear-cut watershed since the regional relationships were not developed for these conditions.

3.3 RELATIONSHIP BETWEEN PEAK AND DAILY MAXIMUM FLOWS

As shown in Table 1, most of the hydrometric stations used in this analysis have shorter records of annual maximum instantaneous flows (QP) than of annual maximum daily mean flows (QD). Consequently, a regional analysis using QP as the dependent variable would have fewer stations with at least 10 years of record and would yield less accurate estimates of large return period flows because of the shorter records.

One way to circumvent this problem is by performing a regression analysis with the mean QP to QD ratios at all stations as shown in Table 2. The ratio of the annual maximum instantaneous flow to the annual maximum daily mean flow is relatively constant from year to year for most basins, especially large ones. However, for basins less than 100 km^2, the difference can be significant, as indicated in Appendix I.

Stepwise multiple regression was performed leading to equations of the form:

$$\log_{10} QP/QD = e + f \log_{10} DA + g \log_{10} SNOW + h \log_{10} \%LS \qquad (2)$$

where QP/QD is the ratio of the maximum annual peak flow to the corresponding daily mean flow;

e is the regression constant;

f, g and h are the regression coefficients;

DA is the drainage area (km^2);

SNOW is the average water content of the snowpack on March 31 (mm); and

%LS is the percentage of the area composed of lakes and swamps.

The results of the regression analysis for the entire Province as well as for each homogeneous flood zone are shown in Table 7 while the range of the appropriate physiographic/climatic variables is in Table 6. For the main stem of the Saint John River, no equation could be developed because the factor explaining the greatest variation was not statistically significant. Consequently, an average value of 1.06 is recommended.

4.0 FLOOD FREQUENCY ENVELOPE CURVES

The use of envelope curves provides a quick and relatively simple method to estimate flood flows. However, the user of these envelope curves must bear in mind that they are less accurate than the other techniques presented in this report.

The envelope curves were developed from the 2, 10, 20, 50 and 100 year return period daily mean flows presented in Table 3 adjusted to instantaneous peaks using the QP/QD ratios of Table 2. A higher peaking factor was used for small basins. In developing the curves, it was determined that the Northwestern and Southern regions could be grouped together, as could the Eastern and Central regions. Consequently, two sets of envelope curves, one for each group of two regions, were prepared as shown in Figures 2 and 3.

The 100 year return period envelope curves were compared to the ones developed for maximum daily recorded flows during the late 1960's (Montreal Engineering Co. Ltd., 1969). The 100 year curves tend to fall between the upper and lower curves for maximum recorded flow developed by Montreal Engineering, approaching the upper limit. This appears

TABLE 7

REGIONAL QP/QD REGRESSION EQUATIONS

$$\log_{10}QP/QD = e + f \log_{10}DA + g \log_{10}SNOW + h \log_{10}\%LS$$

Region	e	f	g	h	Multiple r-square	Standard Error (%)
Province	0.303	- 0.082	-	-	0.519	+14.7, -12.8
Eastern	0.170	-0.037	-	-	0.326	+ 5.4, - 5.1
	0.466	-0.032	-0.138	-	0.594	+ 4.4, - 4.2
Central	0.288	-0.074	-	-	0.906	+ 5.7, - 5.4
Southern	0.326	-0.073	-	-	0.167	+24.1, -19.4
	0.291	-0.045	-	-0.091	0.519	+18.9, -15.9
Northwestern	0.291	-0.082	-	-	0.596	+13.0, -11.5
Saint John main stem	-- No equation -- use QP/QD = 1.06 --					

Note: If the regression equations generate a QP/QD less than unity, which is possible for very large basins, a QP/QD ratio of 1.0 should be used.
The QP/QD equations for the Eastern and Southern regions are not statistically significant, but were nonetheless included because the Province-wide equation was biased for these regions. A comparison between actual QP/QDs for the Eastern region and predicted QP/QDs from the Province-wide equation shows that the Province-wide equation almost always predicts too large a QP/QD ratio. Similarly, for the Southern region west of the Saint John River, the QP/QD is overpredicted by the Province-wide equation, while it is almost always underpredicted for the Southern region east of the Saint John River.

reasonable since the envelope curves presented herein refer to instantaneous flows.

In general, the use of the curves presented in this report will tend to provide a higher flow estimate. However, for small and/or steep watersheds, especially those draining into the Bay of Fundy, the curves will likely underestimate flood flows. On the other hand, flood flow estimates for watersheds with a significant degree of storage in the form of lakes and swamps could tend to be significantly overestimated. In such cases, techniques presented in the previous chapter are recommended. Because of the density of hydrometric stations on the Saint John River and the relative ease of application of regional regression equations, the techniques described in the previous chapter on regional flood frequency analysis are recommended for all locations along the river.

Equations of the form $QPT = c\ DA^{d}$ were developed to describe the envelope curves. The coefficients c and d are on Figures 2 and 3.

INSTANTANEOUS FLOW ENVELOPE CURVES
NORTHWESTERN - SOUTHERN REGIONS

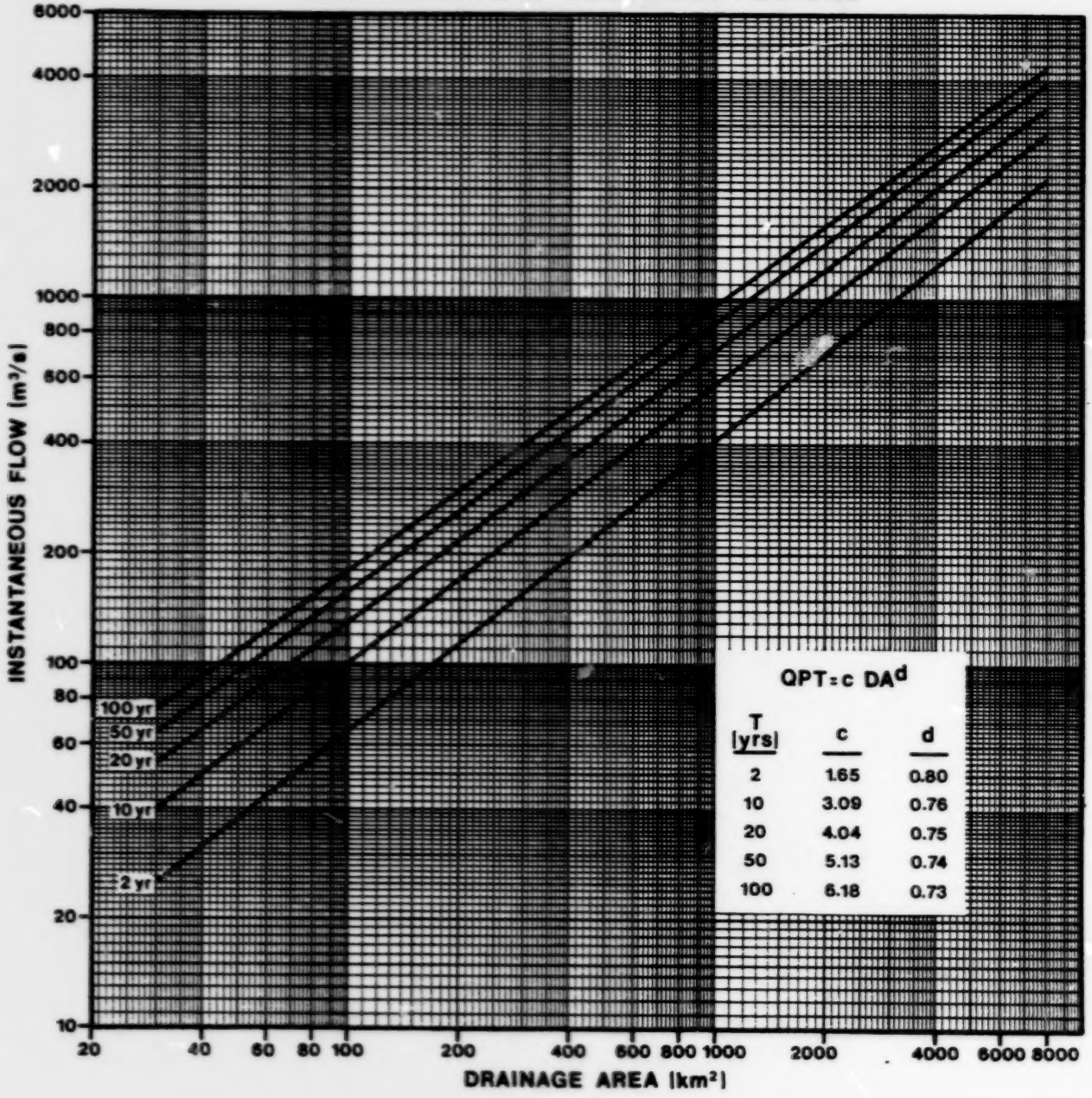

Figure 2

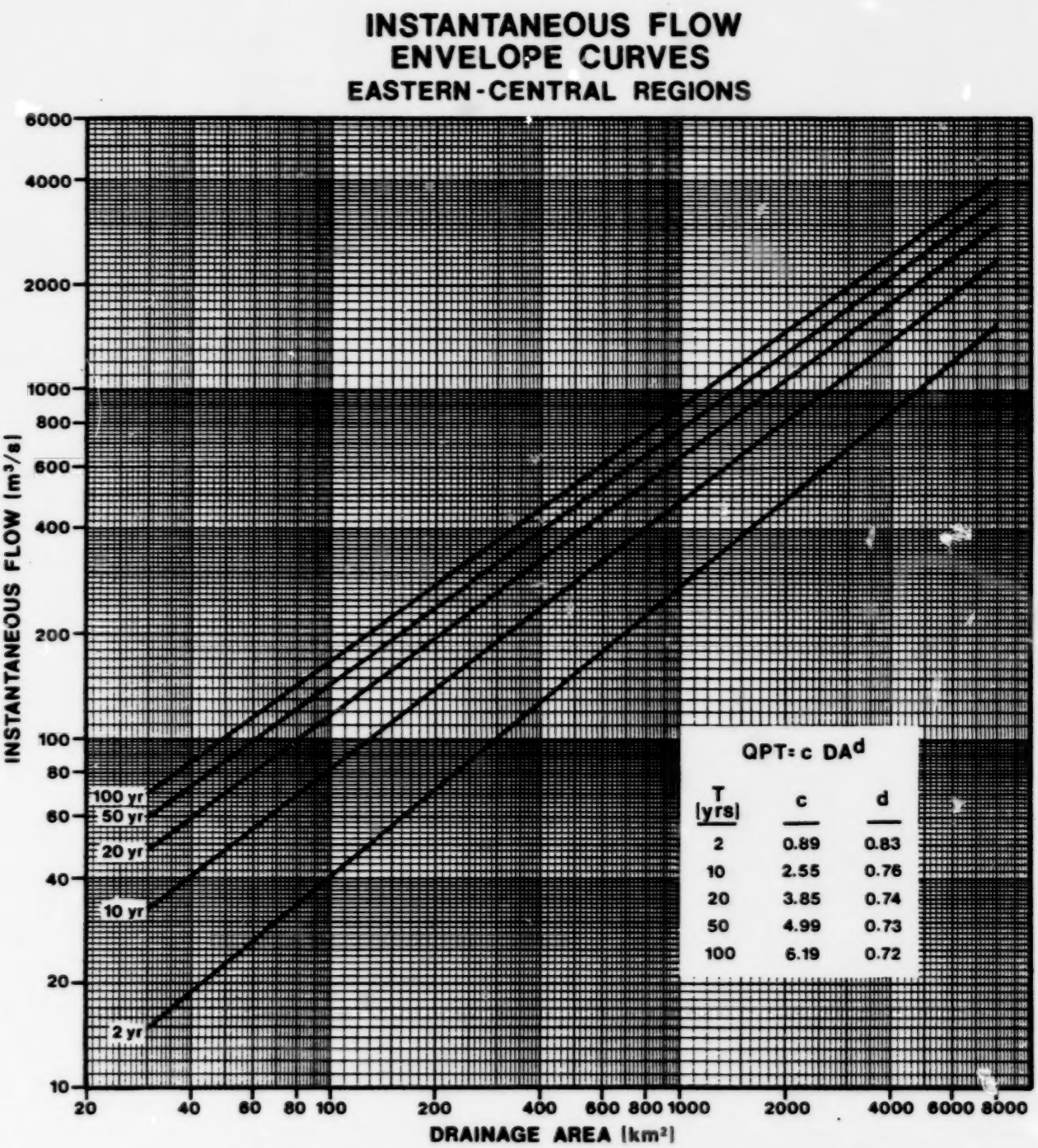
INSTANTANEOUS FLOW
ENVELOPE CURVES
EASTERN-CENTRAL REGIONS
INSTANTANEOUS FLOW (m³/s)
DRAINAGE AREA (km²)
6000
4000
2000
1000
800
600
400
200
100
80
60
40
20
10
20
40
60
80
100
200
400
600
800
1000
2000
4000
6000
8000
100 yr
50 yr
20 yr
10 yr
2 yr
QPT = c DA^d
T (yrs) | c | d
2 | 0.89 | 0.83
10 | 2.55 | 0.76
20 | 3.85 | 0.74
50 | 4.99 | 0.73
100 | 6.19 | 0.72

Figure 3

5.0 PROCEDURE DESCRIPTION AND EXAMPLES

5.1 PROCEDURE OUTLINE

A description of how to estimate design flood flows using the results of this study is given in the section below. The procedural steps given in this description are only intended to provide guidance to the user of the report. In many applications, the user may decide to use an instantaneous flood flow rather than a daily mean flood flow.

The procedure for flood flow estimation for the site of a streamflow gauging (hydrometric) station and for ungauged sites differ and are outlined separately below.

5.1.1 Flood Flow Estimation at Gauged Sites

(1) Identify the station and corresponding number of the hydrometric station for which a flood flow estimate is required. Table 1 lists the full station name and number.

(2) Use the results of the single station frequency analyses (Tables 2 and 3) and abstract daily mean flow(s) for the required recurrence intervals.

(3) More often, an instantaneous flood flow is required, and it can be determined by multiplying the daily mean flow for the required recurrence interval by the ratio of peak instantaneous to daily mean flow (QP/QD) for the station (Table 2).

(4) Single station frequency analysis can be performed using more up-to-date data, if available.

(5) If a natural flow station had less than 10 years of record as of the end of 1985, it will not be in Table 1 and the user is referred to (4) above or to Section 5.1.2 for ungauged sites. Similarly, if QD50 and QD100 estimates were not provided in Table 2, the user may refer to Section 5.1.2.

5.1.2 Flood Flow Estimation at Ungauged Sites

(1) Locate the site on a topographic map and delineate the drainage divide from that point.

The following guidelines may be followed in the selection of National Topographic System (NTS) map scales.

Area in km^2	Scale of Map
> 2000	1:250 000
200 - 2000	1: 50 000
< 200	Use air photos or larger scale maps, using the 1:50 000 scale map as a reference guide.

(2) Determine drainage basin area (DA) in km^2 upstream of the site. Drainage basin area is a parameter in all the regression equations. Use Figure 1 to determine in which region the basin is located. If the area is less than 100 km^2, the regional equations and the envelope curves should not be used except perhaps for comparison purposes with other methods. The techniques mentioned in Appendix I should be employed to obtain design flows for small basins.

(3) For a preliminary flood estimate, use the envelope curves of Figures 2 or 3. For a more accurate estimate, other techniques as detailed in the following steps may be used. Envelope curve flows will tend to be overestimated except for small and/or steep basins where they may be underestimated. For this reason, the user may use the regional equations with a larger return period for comparison purposes. This should reveal if the envelope curve is providing exceedingly large estimates.

(4) Determine whether or not there is a hydrometric station located nearby on the same stream. If a hydrometric station does not exist nearby, proceed to step 5.

If a hydrometric station on the same stream does exist nearby, then proceed as follows:

If the drainage area to the gauge is no more than 10 percent (as a rule of thumb) greater or less than that at the site of interest, then the results of a single station flood frequency analysis for the nearby stations could be adjusted by multiplying it by the ratio of drainage basin areas. An adjustment, based on sound engineering judgement, may also be required to reflect the effect due to differing physiographic and hydrometeorologic parameters.

If the difference in areas is greater than 10%, considerable care must be exercised in prorating basins. Generally, proration should not be used when the difference in area is greater than 50%. The greater the difference in area, the greater the uncertainty in flood estimation will be.

It is preferable to use a prorating exponent less than unity in such cases. Using a unit prorating exponent means that the single station flood frequency estimate is multiplied by the area for the site of interest, and then divided by the area for the hydrometric station. With a prorating exponent, the ratio of the two areas is raised to an exponent and then multiplied by the results of single station flood frequency analysis.

This exponent is obtained from Table 5 as coefficient "a" in the regression equations involving drainage area as the

only significant physiographic factor. When the value of "a" is greater than 1.0, a unit prorating exponent is used. For comparison purposes, flood flows may also be estimated using the regression equations by following steps 5 to 9 as given below.

(5) Select the appropriate constant(s) and coefficients from Table 5 for the desired return period daily mean flood flow(s) and region(s). Where no regression coefficient is given, then the term can be omitted. For example, if no value of the regression coefficient "b" is given, then the term b $\log_{10}$MAP is excluded from the equation.
In most cases, only two coefficients must be determined for use in a regression equation. These are the regression constant "k", and the regression coefficient "a" which is used in the term a $\log_{10}$DA, where DA is drainage area in km^2. Note that two sets of constants and coefficients may be presented for the same return period and region. The lower set produces a flood flow estimate with a lower standard error, but a value must be provided for mean annual precipitation.

(6) Estimate additional parameter (MAP) if required.
Mean annual precipitation (MAP) in mm must be estimated if a value of the coefficient "b" of Table 5 is to be employed. Determine the mean annual precipitation <u>for the drainage basin</u> using Figure 4. A weighted areal average is the best approach. Interpolation with nearby meteorological stations is also acceptable, but not as accurate, especially for large watersheds.

(7) Determine whether or not the parameters fall within the specified ranges for which the equations are considered to be applicable as given in Table 6. The closer the value of any parameter to the limits of the range for that parameter, the greater is the uncertainty associated with the flow estimate(s).

If any parameter value falls outside the specified range, it is recommended that an equation which excludes the problem parameter be considered. In such situations, the estimated flow value will be less reliable due to the increase in the standard error of estimate. The use of an alternate equation will eliminate the problem parameter from computations, but the problem parameter may still have a significant influence on flows.

Drainage area (DA) is the single most important parameter and appears in all the regression equations. If its value falls outside the range, the equation(s) cannot be expected to provide satisfactory flow estimates.

(8) Compute the daily mean flood flow estimate(s) using the equation(s) selected along with the relevant parameters, constant and coefficients.

(9) Compare the flood estimate using another set of equations, either for the entire Province or, if appropriate, for an adjacent region.

Engineering judgement must be exercised. Consideration must be given to all the parameters that may affect flood flows.

If peak instantaneous flood flow estimates are required, proceed with steps 10 through 12. For small basins (less than 100 km^2), the developed regional QP/QD equations should not be used. For such basins, the QP/QD ratio can be extremely high, possibly greater than 5 for steep basins along the Bay of Fundy. For station 1017900, Marley Brook near Ludlow, Maine, a QP/QD ratio as high as 5.88 was recorded. The reader is referred to Appendix I for the determination of instantaneous flows for small basins.

(10) Select appropriate constants and coefficients from Table 7 for the desired return period and region to use in the regression equation to estimate the ratio of peak instantaneous flow (QP) to daily mean flow (QD).If a value less than unity is generated, 1.0 should be used.

(11) Estimate additional parameters if required.

An additional parameter may be estimated for the Southern and Eastern regions in order to produce a QP/QD ratio with a lower standard error. For the Eastern region equation, if a value of the coefficient "g" of Table 7 is to be employed, the average water content of the snow cover on March 31 (SNOW) for the basin will have to be determined by using Figure 5. An areal average, as was the case for MAP, is the most accurate approach.

For the Southern region, if a value of the coefficient "h" of Table 7 is to be employed, the percentage of lakes and swamps %LS must be determined by planimetry from topographical maps. Larger scale or 1:50 000 topographic maps should always be used except for basins less that 200 km^2 where the use of 1:10 000 maps is recommended. Maps

at a scale of 1:250 000 or smaller should never be used because there are often many small lakes and these are not depicted on 1:250 000 scale maps. For consistency with the data base shown in Table 4, if the river is wide enough for both banks to appear on a 1:50 000 scale map, then the area of the river should be counted as lake area. The delineation of the area of swamp can be somewhat subjective and is the only physiographic parameter where there is cause for concern. Since the determination of %LS can be very time-consuming, consideration should be given to the acceptable standard error before proceeding.

(12) Because QP/QD and physiographic variables are not as closely related as daily mean flood flows and physiographic variables are, as indicated by the lower multiple r-squares of Table 7, it is wise to use a number of applicable equations and select the largest QP/QD among them. Once the QP/QD ratio has been determined, multiply it by the value of daily mean flow QD to obtain the peak instantaneous flow, QP.

5.2 ILLUSTRATIVE EXAMPLES

The following examples should be of assistance in understanding the above procedures.

Example One: **ESTIMATION OF DAILY MEAN FLOOD FLOWS AT A STREAM GAUGING SITE.**

Determine: The daily mean 100 year return period flood flow, QD100, for the Saint John River at Fort Kent.

Drainage area: From Table 1 entitled "Summary of Hydrologic Information for Selected Hydrometric Stations", the drainage area upstream of the Saint John River at Fort Kent, Station No. 01AD002, is 14 700 km^2.

Solution: (1) Single Station Frequency Analysis

Using Table 1, station Saint John River at Fort Kent, is identified as Station No. 01AD002. From Table 2, entitled "Results of Single Station Flood Frequency Analyses for Entire Period of Record", the QD100 flood flow of 4490 m^3/s can be obtained. An estimate of QD100 for the Saint John River at Fort Kent can also be obtained from Table 3 entitled "Results of Single Station Frequency Analyses Using 1970-85 Period with Historical Analysis" as 3900 m^3/s. If more data are available, i.e. since 1985, a single station flood frequency analysis could be performed.

(2) Regional Flood Frequency Analysis

From Table 5 entitled "Regional Regression Equations", the regression coefficients for use in the regional regression equation for the main stem of the Saint John River are k = -0.311 and a = 0.943 for the 100 year return period.

Substituting the values into the equation

$$\log_{10} QD100 = k + a \log_{10} DA;$$

yields

$$\log_{10} QD100 = -0.311 + 0.943\ (4.167);$$

which simplifies to

$$\log_{10} QD100 = 3.619.$$

Therefore,

$$QD100 = 10^{3.619} = 4160\ m^3/s.$$

Results:

Estimates of the 100 year return period daily mean flow for the Saint John River at Fort Kent (Station No. 01AD002) have been obtained as follows:

From the single station frequency analysis,

for the entire period of record - 4490 m^3/s

for the 1970-1985 period - 3900 m^3/s

Using the Saint John River main stem equation - 4160 m^3/s

Commentary:

The Province-wide regression equation should not be used for the estimation of flood flows along the main stem of the Saint John River. Because gauging stations along the main stem of the Saint John River have much larger drainage areas than other stations in New Brunswick, all but one of the Saint John River gauging stations had to be excluded during the development of the Province-wide equation. Neither should the regression equations for the Northwestern, Central, Eastern or Southern regions be used to estimate Saint John River flood flows. This example utilized the results of a single station flood frequency analysis performed for a gauging station with an adequate record of natural streamflows. For most project sites, such information will not be available. In choosing a value of QD100 to use for design purposes, engineering judgement must be exercised in order to evaluate the acceptable degree of risks based upon several factors, including but not necessarily limited to, the cost and importance of the structure. Experienced designers often choose the largest estimate as it provides a greater degree of safety, especially when there is risk to life and limb.

Example Two: ESTIMATION OF DAILY MEAN FLOOD FLOWS AT AN UNGAUGED SITE

Usually, streamflow gauging stations are not located adjacent to or in the vicinity of a proposed project, and it is necessary to use the regional regression equations, or some other means, to estimate the flood flows at these ungauged locations. In the previous example, there was only one regional regression equation that was applicable. In this example, a site (the ~~Little~~ Southwest Miramichi River near Juniper at the Forks) was selected where the choice of regression equation is less obvious.

Determine: The daily mean 20 year recurrence interval flow, QD20, for the ~~Little~~ Southwest Miramichi River near Juniper at the Forks.

Drainage Area: The drainage divide was outlined on 1:50 000 scale topographical maps and the area determined by planimetry to be approximately 673 km^2.

Solution:

From Figure 1 entitled "Homogeneous Flood Regions and Hydrometric Stations Used in the Analysis", it can be seen that the ~~Little~~ Southwest Miramichi River near Juniper at the Forks lies within the Central region. However, the upstream area of the drainage basin borders the Northwestern region. Therefore, the regional regression equations for both the Central and Northwestern regions as well as the Province-wide regression equations will be used in this example and the results compared.

A drainage area of 673 km^2 is within the acceptable range of areas given for the three equations in Table 6 entitled "Range of Independent Variables Used in Regression Equations".

Using the Central region equation:

From Table 5, for a 20 year return period, the values of "k" and "a" to use in the regression equation for the Central region are -0.190 and 0.939 respectively.

Substituting into the equation:

$\log_{10}QD20 = k + a \log_{10}DA$

and solving, yields $QD20 = 10^{2.465} = \underline{292\ m^3/s}$

Using the Northwestern Region equation:

The regression equation for the Northwestern region is also in the form:

$\log_{10}QD20 = k + a \log_{10}DA$

From Table 5, for a 20 year return period, the values of "k" and "a" for use in the regression equation for the Northwestern region are -0.509 and 1.009 respectively.

Substituting into the above equation, and solving, yields:

$QD20 = 10^{2.344} = \underline{221\ m^3/s}$

Using the Province-wide equation:

There are two Province-wide equations with different regression coefficients and with different standard errors.

The equation with the smallest standard error is:

$\log_{10}QD20 = k + a \log_{10}DA + b \log_{10}MAP$

and differs only from the other equation in that an additional term for mean annual precipitation (MAP) has been added.

From Table 5, for a 20 year return period, the values of "k", "a", and "b" to use in the above Province-wide equation are -6.170, 0.910 and 1.980 respectively.

A value of MAP can be extracted from Figure 4 titled "Mean Annual Precipitation (1951 - 1980)" to be 1105 mm. Checking Table 6, MAP is seen to be within the range for which the equation is applicable.

Substituting into the above Province-wide regression equation, and solving, yields:

$QD20 = 10^{2.429} = \underline{269\ m^3/s}$

If larger standard errors are acceptable, the Province-wide equation omitting the b $\log_{10}$MAP term can be used.

From Table 5 for the 20 year return period, the values of "k" and "a" to use in this simpler Province-wide equation can be found to be -0.055 and 0.878 respectively. Note that these regression coefficients are different from those values to be used in the Province-wide equation which includes the b $\log_{10}$MAP term.

Substituting into the Province-wide equation, and solving, yields:

$QD20 = 10^{2.427} = \underline{268\ m^3/s}$

Results:

Estimates of the daily mean 20 year return period flood flows for the ~~little~~ Southwest Miramichi River near Juniper at the Forks have been obtained as follows:

Using the Central region equation	- 292 m^3/s
Using Northwestern region equation	- 221 m^3/s
Using Province-wide equation	- 269 m^3/s
Using simpler Province-wide equation	- 268 m^3/s

Commentary:

Although the drainage basin upstream of the ~~little~~ Southwest Miramichi River near Juniper at the Forks contains several swamps, a ter[illegible]or lake and swamp area does not appear in the three regression equations used. Consequently, the QD20 estimates may be on the high side.

Example Three: **DETERMINATION OF INSTANTANEOUS FLOOD FLOWS**

The previous examples were of daily mean flood flow estimation. For design purposes, it is often necessary to obtain the instantaneous flow, the peak flow that would occur during a flood of specified return period. To determine the instantaneous flood flows using the methods outlined in this report, it is necessary to first determine the daily mean flood flow. A ratio is then used for the determination of instantaneous flow.

Determine: (1) The instantaneous 100 year return period flood flow, QP100, for the Saint John River at Fort Kent; and (2) the instantaneous 20 year return period flood flow, QP20, for the ungauged ~~little~~ Southwest Miramichi River near Juniper at The Forks.

Drainage Areas: From previous examples:

Saint John River at Fort Kent	- 14 700 km^2
~~little~~ Southwest Miramichi River near Juniper at The Forks	- 673 km^2

Solution:

(1) Saint John River at Fort Kent.

In Example One, the 100 year return period daily mean flood flow for the Saint John River at Fort Kent, Station No. 01AD002, was selected as 4160 m^3/s. This example is a continuation of the calculations in order to determine the instantaneous peak flood flow at the same location.

From Table 7, entitled "Regional QP/QD Regression Equations", the ratio for the main stem of the Saint John River is 1.06; therefore

$$QP100 = 1.06\ (QD100).$$

Substituting QD100 = 4160 m^3/s, and solving yields QP100 = 4410 m^3/s. Conversely, the QP/QD ratio at station 01AD002 could have been used since it is available. This is at the discretion of the user. The envelope curves of Figures 2 and 3 cannot be used because the area is out of range.

(2) ~~Tibbie~~ Southwest Miramichi River near Juniper at the Forks.

Example Two provided an estimate of QD20 = 292 m^3/s (using the regression equation for the Central region). The regional regression equation to determine the ratio of peak instantaneous to daily mean flows for the Central region and for the entire Province is of the form:

$$\log_{10} QP/QD = e + f \log_{10} DA$$

From Table 7, values of "e" and "f" for the Central region equation are obtained as 0.288 and -0.074 respectively.

Substituting these values and DA = 673 km^2 yields:

$$QP/QD = 10^{0.079} = 1.20$$

Similarly, the Province-wide QP/QD equation yields a ratio of 1.18.

The peak instantaneous discharge for the 20 year return period flood can thus be determined:

$$QP20 = 1.20\ (QD20)$$

$$QP20 = 1.20\ (292\ m^3/s) = 350\ m^3/s$$

From the envelope QP20 curve of Figure 3, QP20 is estimated as 478 m^3/s. The envelope curve clearly overestimates the flow as the QP50 flood using the simplest central region regression equation is 428 m^3/s.

Commentary:

The QP/QD ratios to multiply values of QD obtained using the regional regression equations for daily mean flood flow estimation are, themselves, calculated using regression equations. The coefficients for use with the QD regression and the QP/QD regression equations are different and not interchangeable. In the case of the main stem of the Saint John River, the ratio QP/QD is 1.06 and there is no regression equation.

Example Four: DETERMINATION OF A FLOOD FLOW WHEN A HYDROMETRIC STATION IS NEARBY ON THE SAME STREAM

The following example outlines the procedure that may be followed if a hydrometric station is located nearby on the same stream (Refer to Step 4 for ungauged sites, Section 5.1.2).

Determine: The daily mean 50 year return period flood flow, QD50, for the Upsalquitch River at Robinsonville.

Drainage Area: Streamflow gauging station No. 01BE001, Upsalquitch River at Upsalquitch, is nearby. From Table 1, the drainage area at the gauging station is 2270 km^2.

The drainage divide for the portion of the Upsalquitch River basin upstream of Robinsonville but downstream of the gauging station was outlined on 1:50 000 scale topographical maps. The drainage area of this portion of the basin was then determined by planimetry to be approximately 62.3 km^2.

The drainage basin of the Upsalquitch River at Robinsonville is thus 2270 km^2 + 62.3 km^2 = 2332 km^2.

Solutions:

The drainage areas of the Upsalquitch River basins at the gauging station and at Robinsonville differ by less than 10%. The results of the single station frequency analysis for the Upsalquitch River at Upsalquitch can thus be used.

From Table 2 for Station No. 01BE001, the QD50 flow is 746 m^3/s.

Prorating using drainage basin area can be performed as follows:

$$\text{QD50 at Robinsonville} = (746\ m^3/s)\ \frac{2332\ km^2}{2270\ km^2} = \underline{766\ m^3/s}$$

Estimation of flood flows can also be done using the regression coefficients for the area term as an exponent.

From Table 5, a = 0.864; thus

$$\text{QD50} = 746\ \left(\frac{2332}{2270}\right)^{0.864} = \underline{764\ m^3/s}$$

The Province-wide and Northwestern region regression equations can also be used (similar to previous examples) to obtain flood flow estimates of <u>915 m^3/s</u> and <u>902 m^3/s</u> respectively.

Results:

QD50 flood flow estimates for the Upsalquitch River at Robinsonville:

Prorating using ratio of drainage areas	- 766 m^3/s
Proration using regression exponent	- 764 m^3/s
By using Province-wide regression equation	- 915 m^3/s
By using Northwestern regression equation	- 902 m^3/s

Commentary:

As the hydroclimatic and physiographic conditions of the lower basin do not differ greatly from that of the entire basin, prorating the results of the single station frequency analysis for the gauging station at Upsalquitch should be acceptable. However, it may be wise to use a higher flow estimate, depending on the degree of risk involved.

6.0 REFERENCES

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APPENDIX I

ESTIMATION OF FLOOD FLOWS FOR SMALL DRAINAGE BASINS

(AREA LESS THAN 100 KM^2)

Introduction

For the purpose of this report, a basin can be considered small if its drainage area is less than 100 km^2. A small basin may be defined as one that is so small that its sensitivity to short duration, high intensity rainfall and to land use is not suppressed by channel characteristics (Chow, 1964).

Factors affecting runoff cause the hydrologic behaviour of large drainage basins to differ from small drainage basins. The effect of overland flow rather than channel flow is a dominating factor affecting peak runoff in small basins (Chow, 1964). Land use, vegetation, topography and geology are often important considerations in the estimation of flood flows for small basins.

Methods that can be used to estimate small basin flood flows include prorating, area-discharge relationships, the rational formula, regional regression equations, overland flow hydrographs, synthetic unit hydrographs and hydrologic modelling. All methods have limitations resulting from the requirements for data or basic underlying assumptions.

Prorating

The determination of a flood flow at an ungauged site by multiplication of a known flood flow for a similar gauged basin by the ratio of drainage basin areas raised to some power (usually unity) is referred to as prorating. In equation form, prorating is as follows:

$$Q_1 = Q_2\left(\frac{A_1}{A_2}\right)^x$$

in which Q_1 = the peak or daily mean flow (m^3/s) to be determined for the ungauged site;

Q_2 = the peak or daily mean flow (m^3/s) at the gauged site as can be determined from a single station flood frequency analysis;

A_1 = the drainage area upstream of the ungauged site at which a flood flow estimate is required (km^2);

A_2 = the drainage area of the gauged basin (km^2); and

x = an exponent (usually unity).

Since there are a number of hydrometric stations of drainage area less than 100 km^2 (see Table A-1) for which frequency analyses are available in this report, these can be employed to estimate floods at ungauged sites through proration. However, the results are only transferable to basins similar in area (plus or minus 20 percent), land use and physiography which are in the same general vicinity. Their results should not be used for ungauged basins very different in size, land use or physiography, or of a different location in the Province.

The QDT estimates from Tables 2 and 3 can be prorated and then multiplied by a QP/QD ratio in order to obtain an instantaneous peak flow. Because the QP/QD ratio of small basins is highly variable, in order to provide a peak flow estimate on the high side, the user may wish to employ a QP/QD ratio mid-way between the mean ratio of Table 2 and the maximum recorded ratio of Table A-1.

Area-Discharge Relationship

A simple area-discharge relationship has been developed by the New Brunswick Department of Municipal Affairs and Environment. It is as follows:

$Q = 1.64\ A$

where Q is the design discharge (m^3/s); and

A is the drainage area (km^2) of a basin 20 km^2 or less.

This relationship was developed from an envelope curve of maximum observed flows for small gauged watersheds (<20 km^2). It does not take into account differences in basin topography or hydroclimatic conditions. Therefore, the relationship should be used only for determination of rough (approximate) estimates of flood flow. For basins along the Bay of Fundy, this method may underestimate flows.

The Rational Method

The rational method for estimating peak flows has been widely accepted for small basin flow estimation, urban storm sewer design (Gray, 1970) and airport drainage design (Chow, 1964). The rational method is based on the concept that the maximum rate of runoff occurs when the entire basin is contributing to the flow at the outlet as a result of a uniform intensity and distribution of rainfall over the basin. For large drainage basins, rainfall will likely be unevenly distributed over the catchment area and runoff water originating in very remote parts of the drainage basin may arrive too late at the outlet to contribute to peak flows. Therefore, for these reasons, the rational method should generally be restricted to drainage basins less than 15 km^2 in area.

In metric units, the rational equation is:

$Q_p = 0.278\ c\ i\ A$

where Q_p = peak rate of runoff (m^3/s);

c = runoff coefficient;

i = rainfall intensity (mm/hr) of a storm whose duration is equal to the time of concentration of the basin; and

A = area of the drainage basin in km^2.

The runoff coefficient c can be obtained from tables. Considerable judgement in selecting the appropriate runoff coefficient for a particular application must be exercised as the magnitude of the runoff coefficient varies with the type, vegetative cover, and slope of the ground surface. Runoff coefficients vary with rainfall intensity and frequency, but are often assumed to be the same for all storms on a given watershed. However, the runoff coefficients presented in tables are applicable only to a specific range of storm frequency, and may have to be increased for less frequent, higher intensity storms.

Rainfall intensity is obtained from rainfall - intensity - duration curves produced using climatic data obtained at the nearest weather station in a hydroclimatic zone similar to the basin being studied. Selection of a value of rainfall intensity is based upon the time of concentration of the basin and the frequency of occurrence of the design flood.

The time of concentration is the time required for surface runoff from the most remote part of the drainage basin to reach the point along the watercourse for which the peak rate of runoff is being determined.

Several equations have been developed for determining the time of concentration, including the following equation in metric units:

$$t_c = 0.0195\ L^{0.77}\ \left(\frac{H}{L}\right)^{-0.385}$$

in which t_c = time of concentration (min);

L = maximum length of travel of water (m); and

H = the difference in elevation between the most remote point on the basin and the outlet (m).

Drainage area A is obtained by planimetry once the drainage divide has been delineated on suitable topographical mapping. For small basins, it is recommended that 1:10 000 scale topographical maps or larger scale urban mapping be used when available.

The rational method can be used to estimate peak flows in small (15 km^2) unregulated basins in New Brunswick provided the depression storage is small, and runoff coefficients appropriate for New Brunswick conditions are selected. However, potential users must be aware of the limitations of the rational method, and consider the applicability and suitability of the method in relation to his or her particular needs for accuracy and safety in flood flow estimation.

Regional Regression Equations

The regional flood frequency equations, previously presented in this report, are not truly applicable to small basins. Their development was based in part upon the results of single station flood frequency analyses for selected hydrometric stations (Table 1), most of which are greater than 100 km^2 in area. The developed equations can be applied to smaller size basins in order to obtain a rough estimate, but a significant difference in physiography between the basin of interest and the basins for which the equations were derived may make these equations totally inapplicable.

Development of regional regression equations for determination of flood flows in small basins may be possible. However, the present streamflow data base in New Brunswick is insufficient for this purpose.

Synthetic Unit Hydrographs

Since physical characteristics of a drainage basin are constant, it can be assumed that similarly shaped hydrographs will be produced from storms of similar rainfall characteristics. A typical hydrograph for a basin is the unit hydrograph, defined as the hydrograph of direct runoff resulting from one centimetre of uniform effective rainfall during a specified period of time or duration. A synthetic unit hydrograph is a means of deriving unit hydrographs for ungauged streams. The time and magnitude of peak flow and the time base of the synthetic unit hydrograph are usually estimated by relating hydrographs to basin characteristics.

Various methods of deriving unit hydrographs and synthetic unit hydrographs are presented in most hydrology books (e.g. Chow, 1964, Linsley, Kohler and Paulhus, 1975; Gray, 1970). It should be remembered that application of any method should be done only after underlying assumptions have been studied and understood.

Overland Flow Hydrographs

More detailed hydrologic analysis of urban areas (less than 5 km^2 in area) can be done by evaluating overland flow. Horton proposed an equation for overland flow considered suitable for turbulent flow with high discharge on natural surfaces, whereas Izzard developed a dimensionless hydrograph for surface flow which is presumed largely applicable to laminar flow on developed surfaces (Chow 1964). The major problem in applying such methods is defining the characteristics of the surface (Linsley, Kohler and Paulhus, 1975).

Hydrologic Modelling

Hydrologic modelling can be used to obtain more reliable estimates of flood flows for small basins. However, its application requires considerably more effort and time than the methods previously discussed and thus hydrologic modelling may be impractical for very small projects.

Modelling surface runoff from watersheds can be done using the computer program HYMO, which transforms rainfall data into runoff hydrographs which can then be routed through stream valleys or reservoirs (Williams and Hann, 1973). For transformation of the input into runoff hydrographs, the program uses a synthetic unit hydrograph technique and Soil Conservation Service rainfall-runoff relationships to generate hydrographs for basin subareas. These hydrographs are added together and routed downstream until the storm event hydrograph at the outlet is obtained. HYMO has been used for flood damage reduction studies in New Brunswick.

A good review of the hydrologic processes involved in modelling runoff from small basins along with a comprehensive list of existing models are available in a volume entitled "Hydrologic Modelling of Small Watersheds" (Haan et al, 1982).

TABLE A-1

HYDROMETRIC STATIONS SMALLER THAN 100 KM^2

Station No.	Drainage Area (km^2)	Maximum Recorded QP/QD Ratio
1017900	3.81	5.88
01AL004	3.89	2.72
01AL003	6.48	2.89
01AK005	26.9	2.30
01BV005	29.3	1.63
01BU004	34.2	2.89
01AN001	34.4	1.48
01AR008	43.0	1.56
01DL001	63.2	2.17
01BJ004	88.6	1.29

REFERENCES FOR SMALL BASIN APPLICATIONS

Chow, Ven Te: "Runoff" Section 14 of Handbook of Applied Hydrology, Ven Te Chow, Editor-in-Chief. McGraw-Hill Book Company, Toronto, 1964.

Gray, Donald M.: "Peak Flow - Rainfall Events", Section VIII of Handbook on the Principles of Hydrology. Donald M. Gray, Editor-in-Chief. A Water Information Centre Publication, 1970.

Haan, C.T., H.P. Johnson, and D.L. Brakensiek (editors): Hydrologic Modelling of Small Watersheds, American Society of Agricultural Engineers Monograph No. 5, Michigan, U.S.A., 1982.

Linsley, Ray, Max Kohler and Joseph Paulhus: Hydrology for Engineers - Second Edition, 1975.

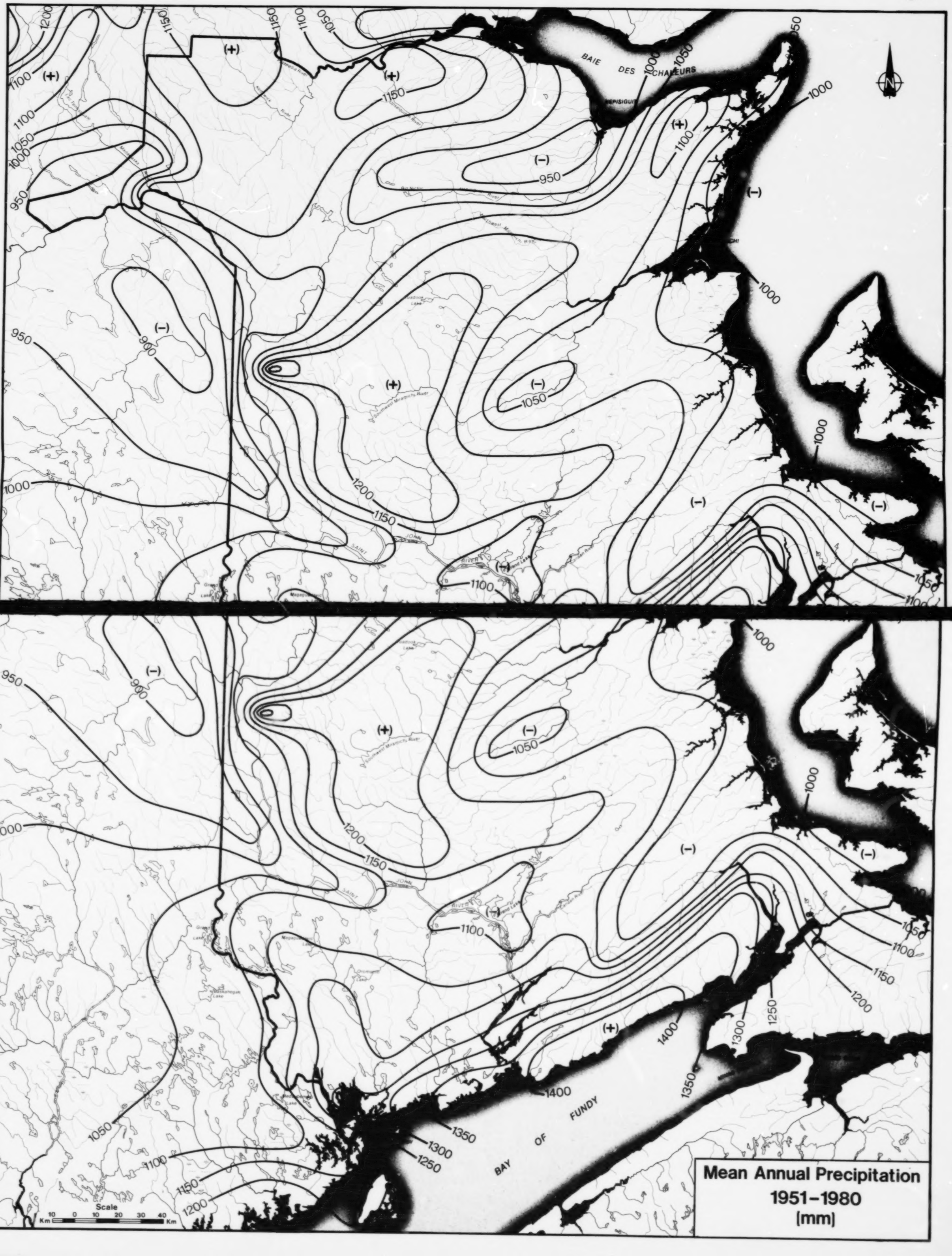
Williams, J.R. and R.W. Hann: HYMO; Problem Oriented Computer Language for Hydrologic Modelling - Users Manual, U.S. Dept. of Agriculture, 1973.

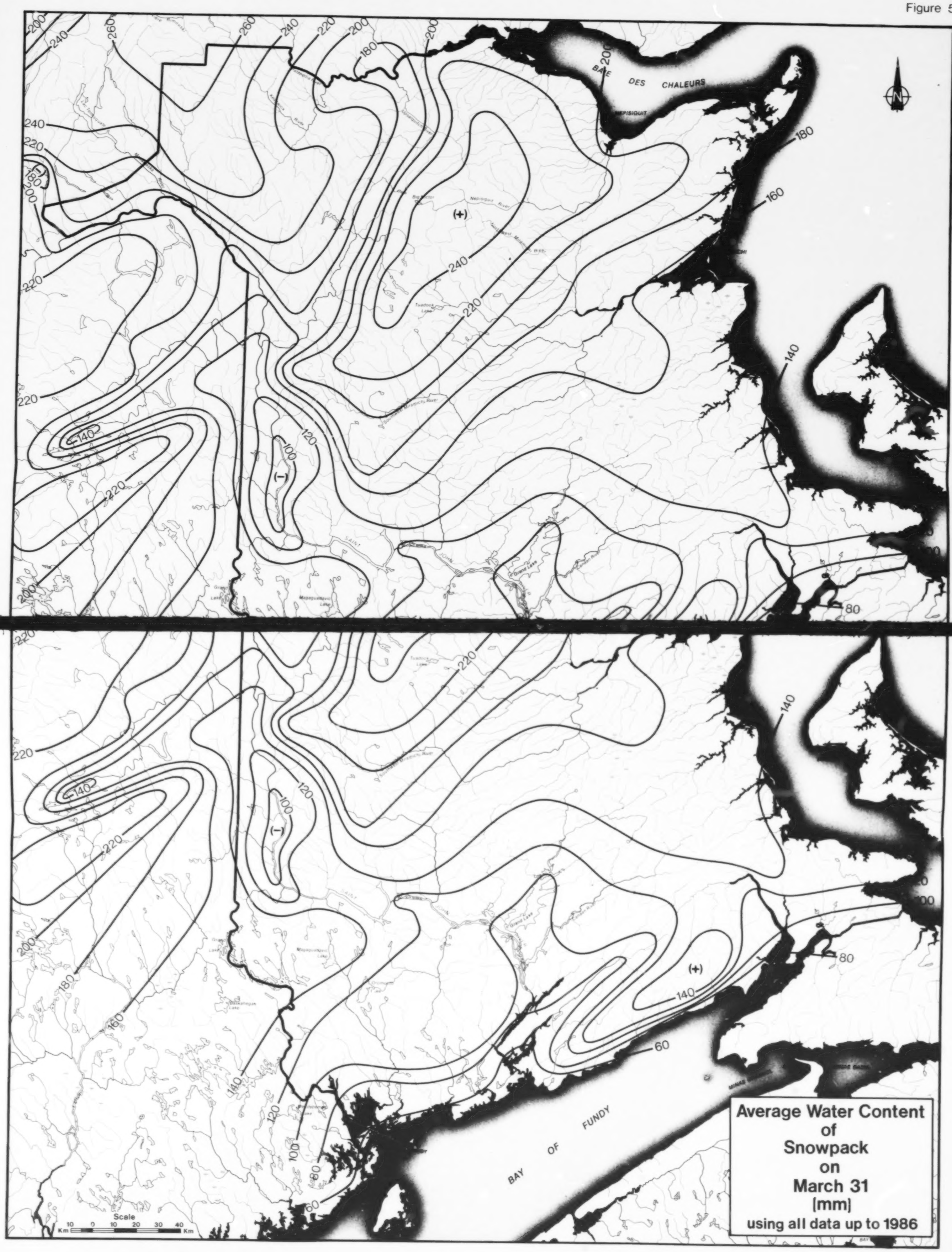
Figure 1

Homogeneous Flood Regions and Hydrometric Stations used in the Analysis

NOTE: The Main Stem of the Saint John River is a Fifth Region.
Canadian Stations are abbreviated (e.g. 1AD2 = 01AD002)

Figure 4


BAIE DES CHALEURS
EPISIGUIT
BAY OF FUNDY
SAINT JOHN RIVER
Southwest Miramichi River
Restigouche River
Kedgwick River
Upsalquitch River
Nepisiguit River
Tetagouche River
Middle River
Northwest Miramichi River
Southwest Miramichi River
Renous River
Canaan River
Grand Lake
Mamozekel Lake
Baskahegan Lake
Scale
10 0 10 20 30 40
Km Km
Mean Annual Precipitation
1951–1980
(mm)


BAIE DES CHALEURS
RESTIGOUCHE
MIRAMICHI
BAY OF FUNDY
SAINT JOHN
Grand Lake
Tuadook Lake
Southwest Miramichi River
Nepisiguit River
Big Hector
Mapequahavic Lake
Oromocto Lake
Eskahegan Lake
Scale
10 0 10 20 30 40
Km Km
Average Water Content
of
Snowpack
on
March 31
[mm]
using all data up to 1986